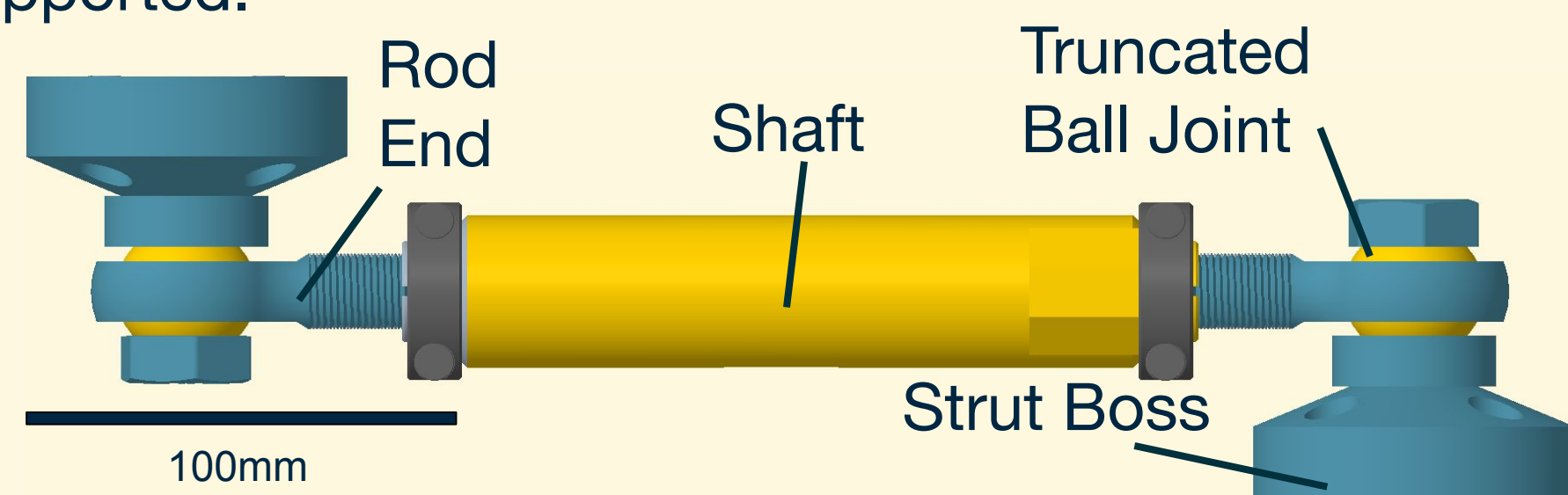


Abstract

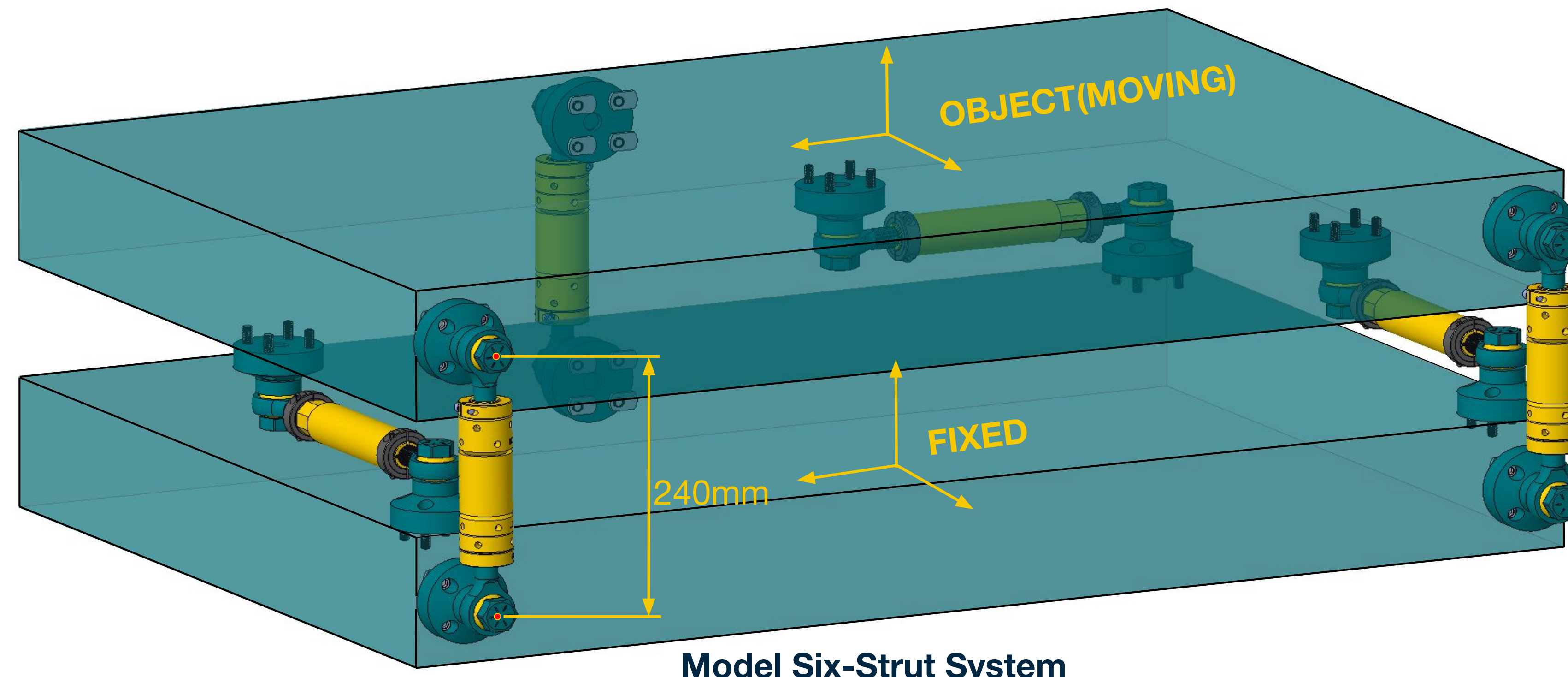
Six-Strut Systems are parallel manipulators designed at Lawrence Berkeley National Laboratory. It enables precise translations in X, Y, and Z, and rotations in yaw, pitch, and roll. Adjusting one strut causes a coupled movement in the other struts. Currently, the struts are manual; to automate them, linear actuators and kinematics for six-strut systems are needed. Using a rotation matrix and defining two frames, one for the object and one for the fixed frame, equations are made to calculate the strut lengths. With these lengths, linear actuators can be programmed to automate the strut adjustments.

Background

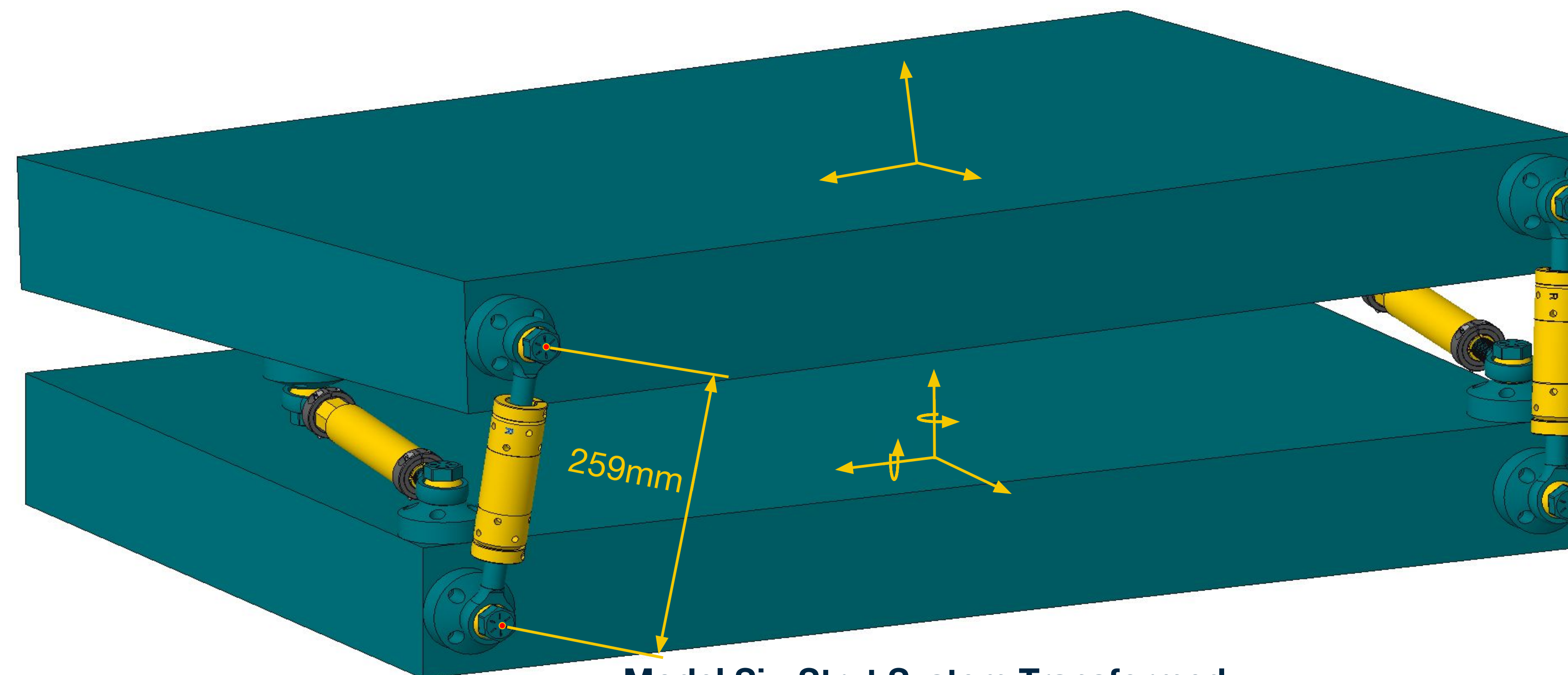
Strut contains two ball joints, one end is fixed, other end moves with object. Shaft and rod ends swivel and rotate at ball joints allowing six degrees of freedom for a plate with six struts. Six struts are necessary to keep the plate supported.



Strut Model: Opposite direction threaded rods screwed into a shaft. Connected with strut bosses with bolted truncated ball joints



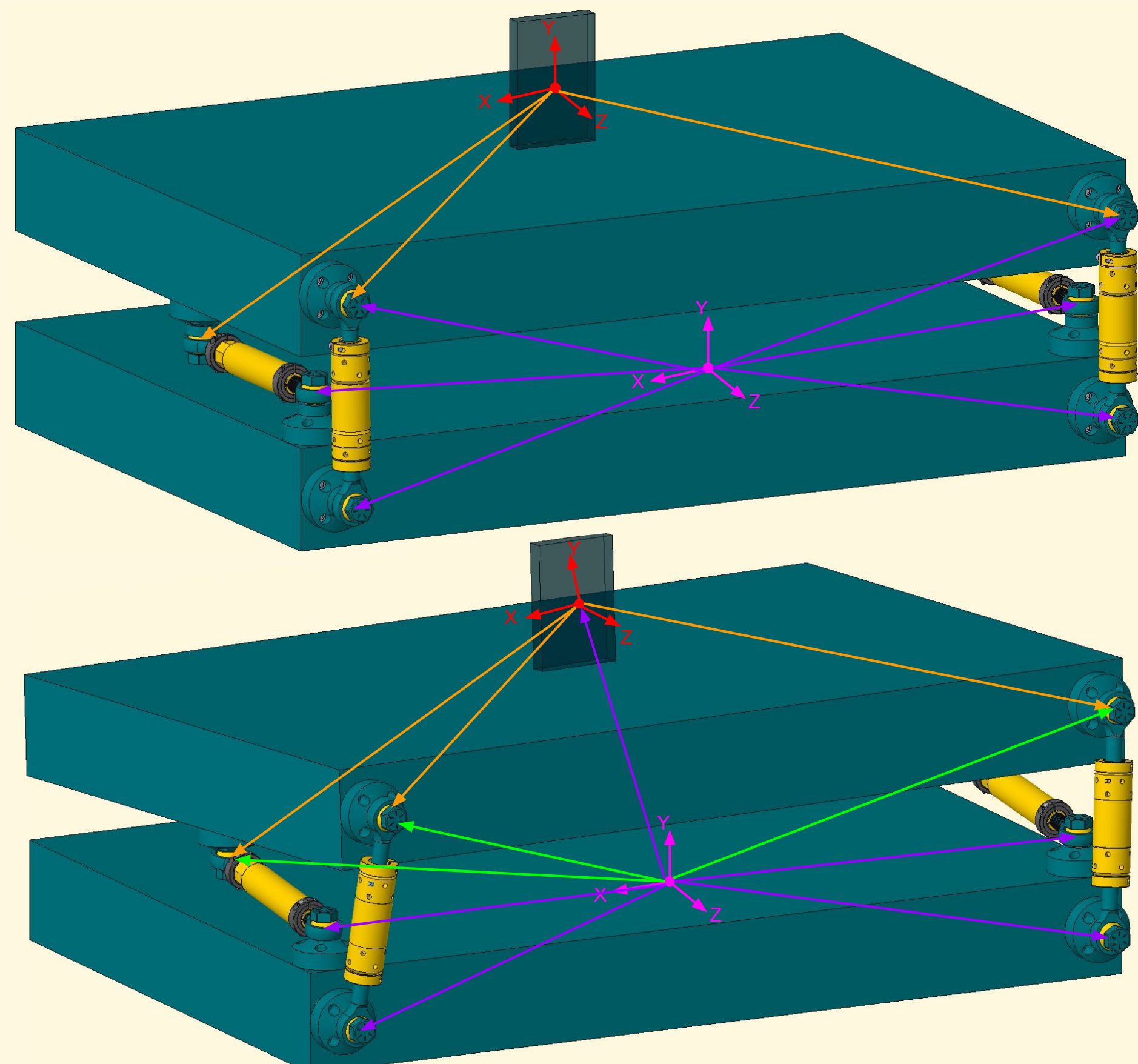
Model Six-Strut System



Model Six-Strut System Transformed

Kinematics

Define two frames, one for object and one for fixed space. Vectors can be made from fixed and object frames to ball joints. Ball joints move resulting in a new vector in fixed frame. Use rotation matrix to find position of new vectors.



Six-Strut Frames and Vectors: Before and After transformation—Moving ball joints have new vectors in fixed frame, Object frame has vectors to moving ball joints.

Strut Length Calculator

- Input object position
- Input addition object position with respect to object

Object Frame Coordinate with respect to fixed frame			
X	Y	Z	
0		0	0

Rotate around additional point with respect to object			
X	Y	Z	
0		0	0

- Fixed Joint Positions in Fixed Frame
- Free Joint Positions in Object Frame

Coordinate for center of Ball Joint 1 (Fixed end)				Coordinate for Ball Joint 2, with respect to plate frame (if both frame are at same point, coordinate should be the same for either frames)			
Strut #	X	Y	Z	Strut #	X	Y	Z
1	0	908.816	-417.15	1	0	1149.03	-417.15
2	495.3	908.816	-417.15	2	495.3	1149.03	-417.15
3	-495.3	908.816	-417.15	3	-495.3	1149.03	-417.15
4	495.3	1038.07	-323.85	4	495.3	1038.07	-38.1
5	-495.3	1038.06	-323.85	5	-495.3	1038.06	-38.1
6	-495.3	1038.07	323.85	6	-209.55	1038.07	323.85

- Translations and rotations

Translation Object			Rotation Object (degrees)		
X (offset)	Y (offset)	Z (offset)	Around X-axis(a)	Around Y-axis(b)	Around Z-axis(g)
0		0	0	0	0

Translation another object w/ respect to initial object			Rotate additional object w/ respect to initial object (degrees)		
X (offset)	Y (offset)	Z (offset)	Around X-axis(a)	Around Y-axis(b)	Around Z-axis(g)
0		0	0	0	0

- Final Output for each strut

Strut Lengths	
Strut Number	Object
S1	240.21
S2	240.21
S3	240.21
S4	285.75
S5	285.75
S6	285.75

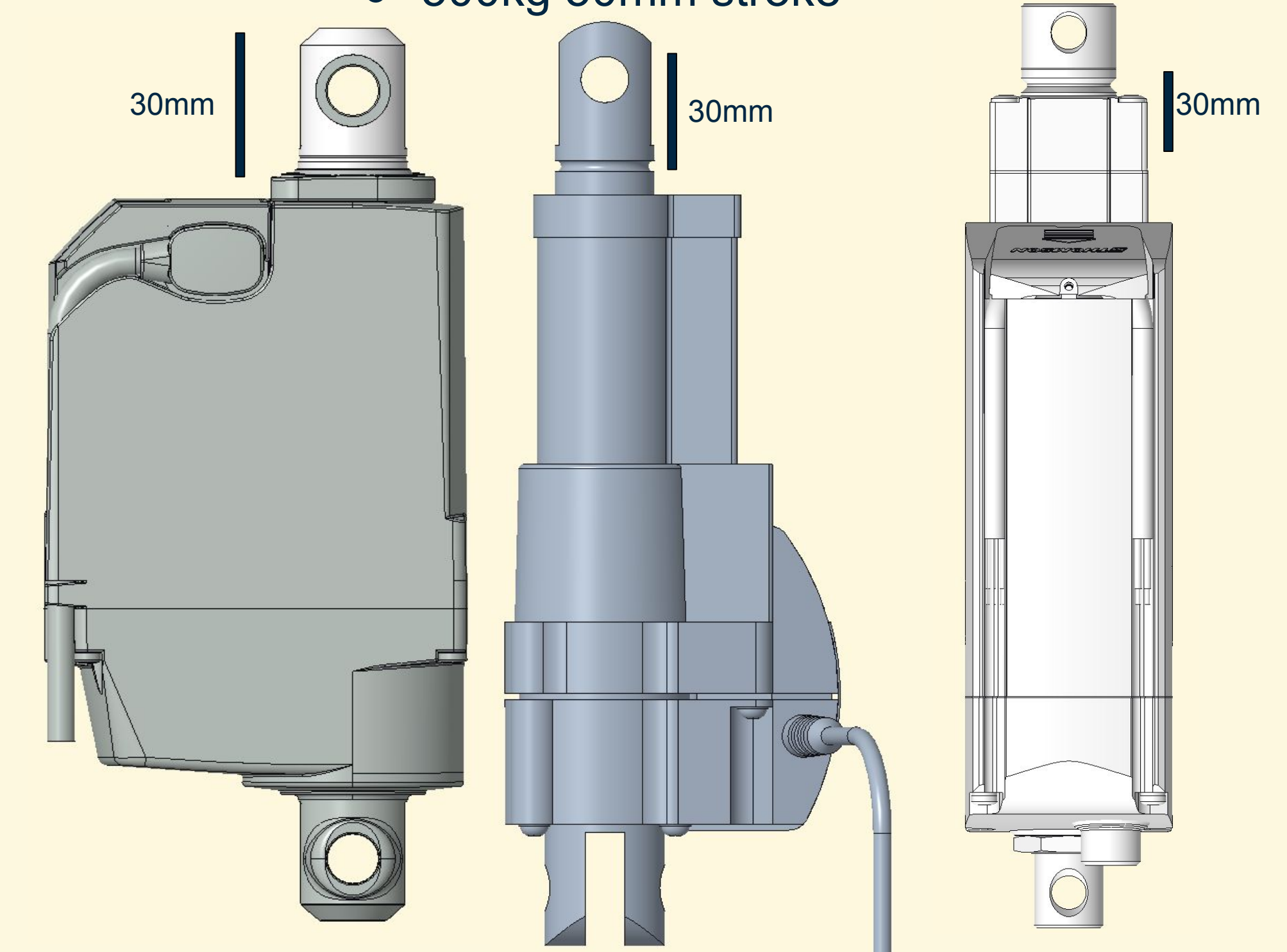
Struts can be adjusted to these lengths to get the desired positions

Linear Actuators

Manually adjusting a strut causes a coupling motion resulting in multiple struts moving. Manual movement can be replaced with linear actuators.

Desired Actuator Specs

- 200kg 30mm stroke
- 200kg 50mm stroke
- 500kg 30mm stroke
- 500kg 50mm stroke



Linear Actuator CAD Models: More actuators are chosen — specific vectors allow for further customizations and variety. Top and bottom of struts have clevis attachments

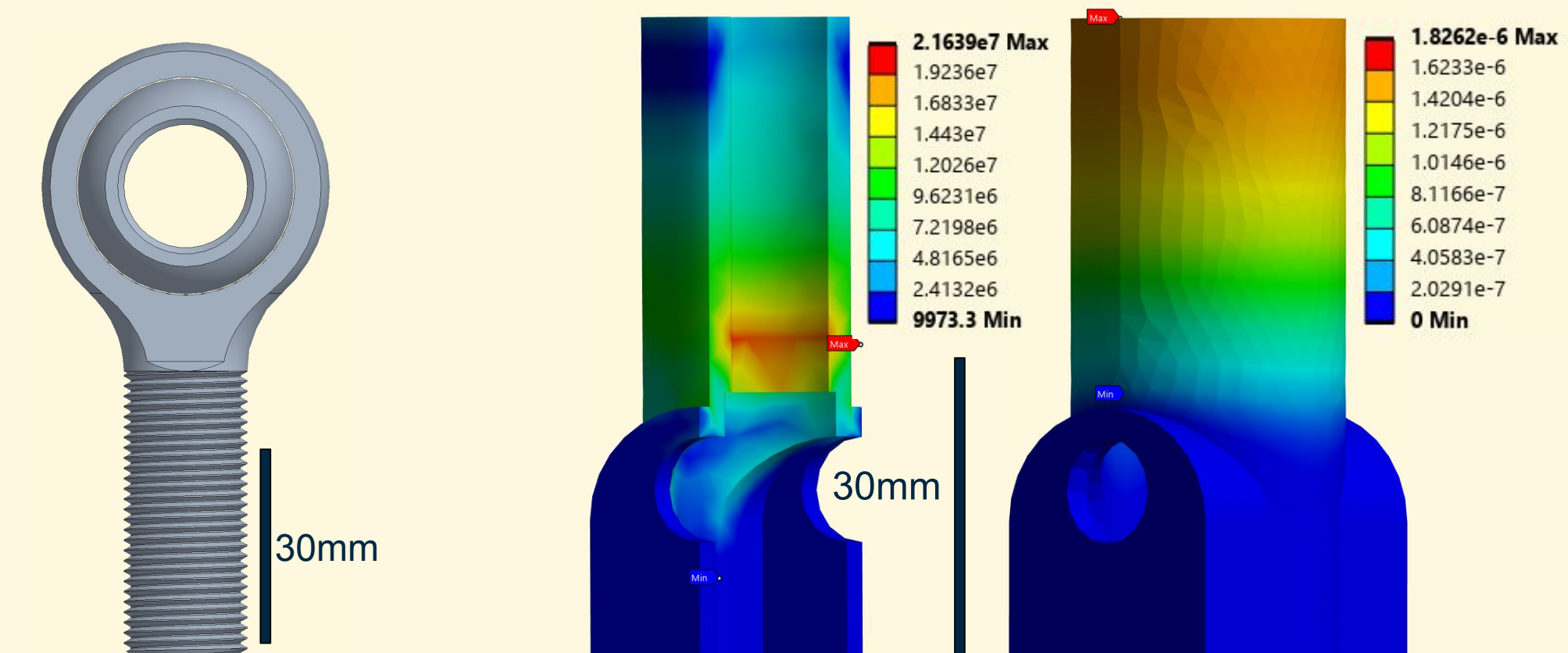
LINAK, "LA23". Available: <https://www.linak-us.com/products/linear-actuators/la23>.

McMaster-Carr, "4267N22". Available: <https://www.mcmaster.com/4267N22/>.

Thomson Linear, "Electrak LL 24". Available: <https://www.thomsonlinear.com/en/product/LL24B020-0100LEXAEEMD>.

Clevis to Rod End Attachment

Struts need a rod end attachment to function. Since most actuators have clevis ends, a custom attachment is made to screw on a rod end to a clevis.



Rod End: screw onto top of Attachment piece —ball joint in center

McMaster-Carr, "60645K18". Available: <https://www.mcmaster.com/60645K18-60645K181/>

Attachment Stress and Deformation: Right image is sectioned— Fixed holes on side to represent bolt on clevis. Force applied on top hole. Force 500N greater than rated

Acknowledgments

This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Science Undergraduate Laboratory Internship (SULI) program.

Thiviru Pulukkuttige Don
SULI Summer 2025 Term

Poster Summary

Six-Strut systems are parallel manipulators that adjust equipment in X, Y, and Z directions, as well as yaw, pitch, and roll rotations. Manual adjustment of each strut at Berkeley Labs is tedious due to coupling effects where one strut causes multiple struts to move. Commercial automated parallel manipulators are expensive and prone to delays when broken. This term, I designed an automated six-strut system with easier repairs and lower costs. I derived the kinematic equations to determine necessary strut lengths for desired position and rotation changes. Linear actuators were selected as automatic struts based on load capacity and stroke length. Custom attachment rod end pieces are designed and stress tested for the linear actuators. In the future the kinematic equations can be used to program the linear actuators using controllers such as a Galil.